Improvement of the power response in contrast imaging with transmit frequency optimization

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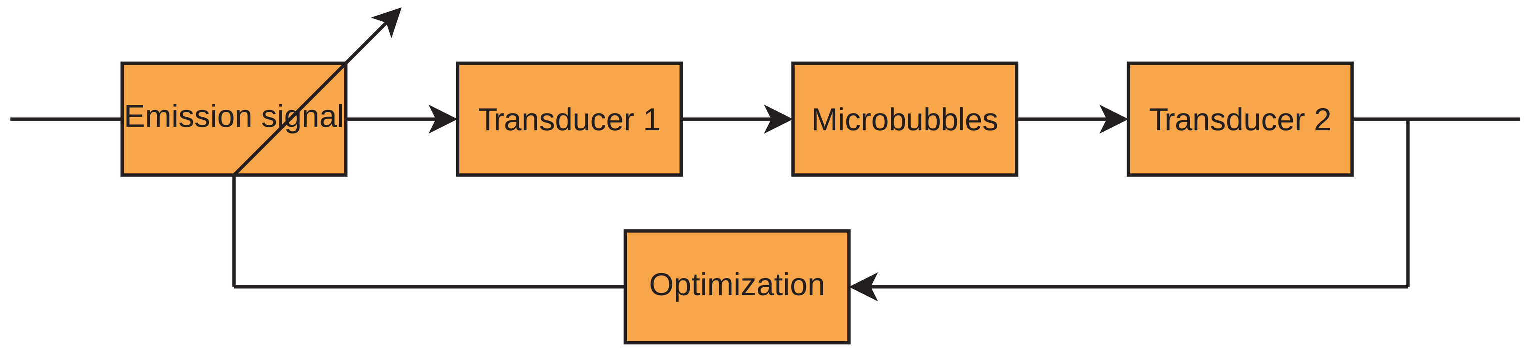
1. Introduction

Ultrasound (US) contrast imaging is being investigated for tissue function and for targeted therapeutic applications with microbubble ultrasound contrast agents (UCA). Currently technical challenge consists in seeking for US excitations which should make possible the optimization of the contrast tissue ratio (CTR). This ratio can be maximized if the microbubbles backscattered power is maximized with the transmit signal.

$$CTR = \frac{E_{bubbles}}{E_{BMF}}, \text{ with } \begin{cases} E_{bubbles} & \text{the microbubbles backscattered power} \\ E_{BMF} & \text{the tissue backscattered power} \end{cases}$$

We tackled the problem in a simple way by proposing an adaptive imaging technique which seeks the transmit frequency that maximizes the backscattered power. That is to disregard these unknown factors, it seemed more judicious to propose an US excitation whose frequency is selected in an adaptive way.

2. Methods

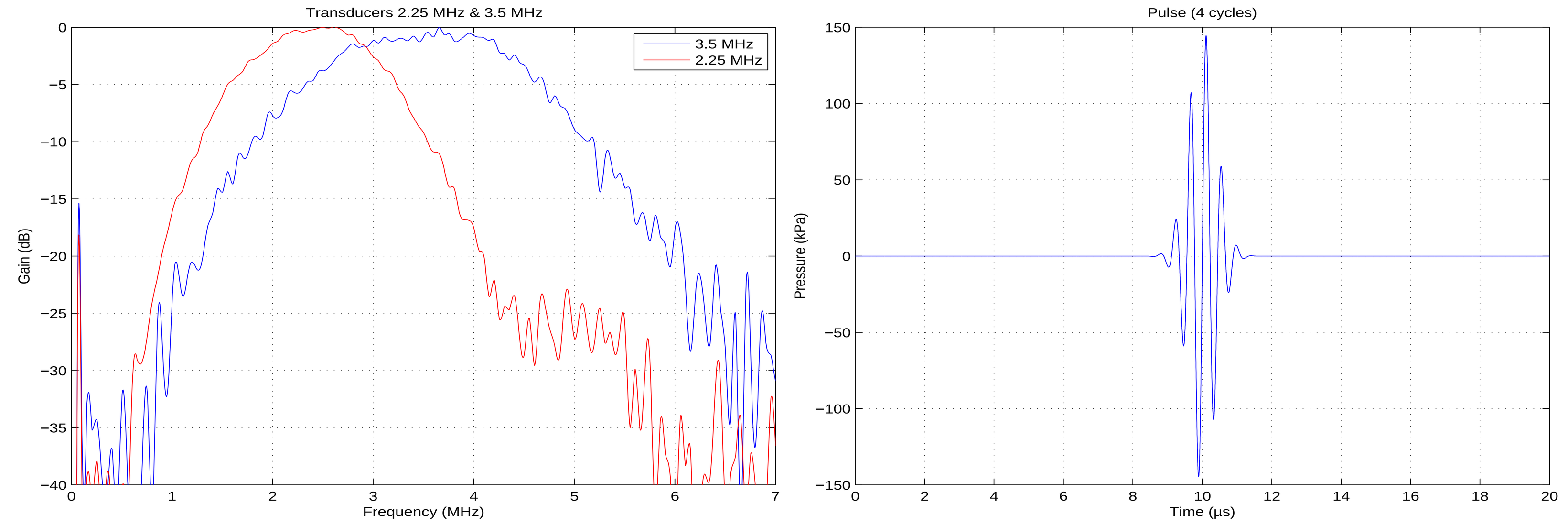


1. Transmit pulse with the frequency f_{old} and a 4 cycles $\rightarrow$ Constant transmit power
2. Repeat (1) twenty times
3. Compensation of bandwidth transducers
4. Linear combination of twenty signals by principal component analysis
5. Backscattered power of the new signal
6. Optimal frequency f_{new} computed by the optimization algorithm $\rightarrow$ maximizing backscattered power
   Two different optimization algorithms
   - Golden section search (GSS)
     Choose two frequencies (f_1 and f_2) around the maximum power.
     Reduce the intervals with a third frequency f_3
   - Gradient ascent (GA)
     steps proportional to the gradient of energy
     $\rightarrow f_{k+1} = f_k + \alpha_k \nabla E(f_k)$
7. $f_{old} = f_{new}$ and return to (1)

3. Materials

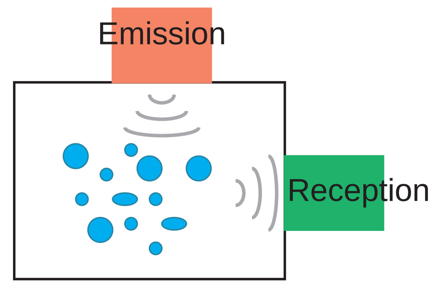
Microbubbles

- Microbulles SonoVue^{TM}: mean diameter of 4.5 μm with shell thickness of 1 nm ; Resonance frequency : $f_R = 2.1$ MHz
- Concentration: 1/2000 diluted solution of Sonovue^{TM}
- Immersed in a blood mimicking fluid (BMF)



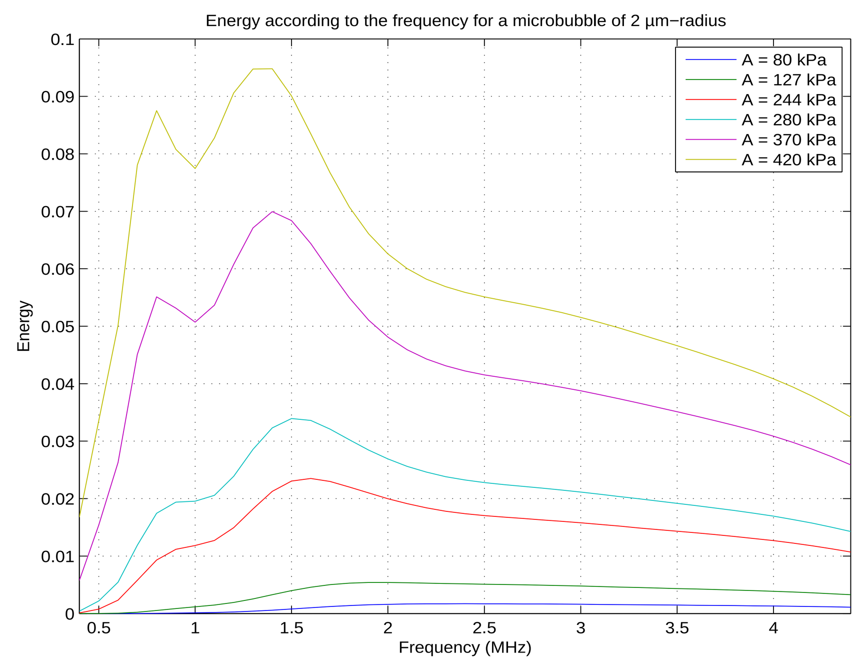
Acoustical Measurements

- Arbitrary function generator piloted by Matlab®
- 2 perpendicular transducers :
  1. Emission : 2.25 MHz - BW 74%
  2. Reception : 3.5 MHz - BW 63%

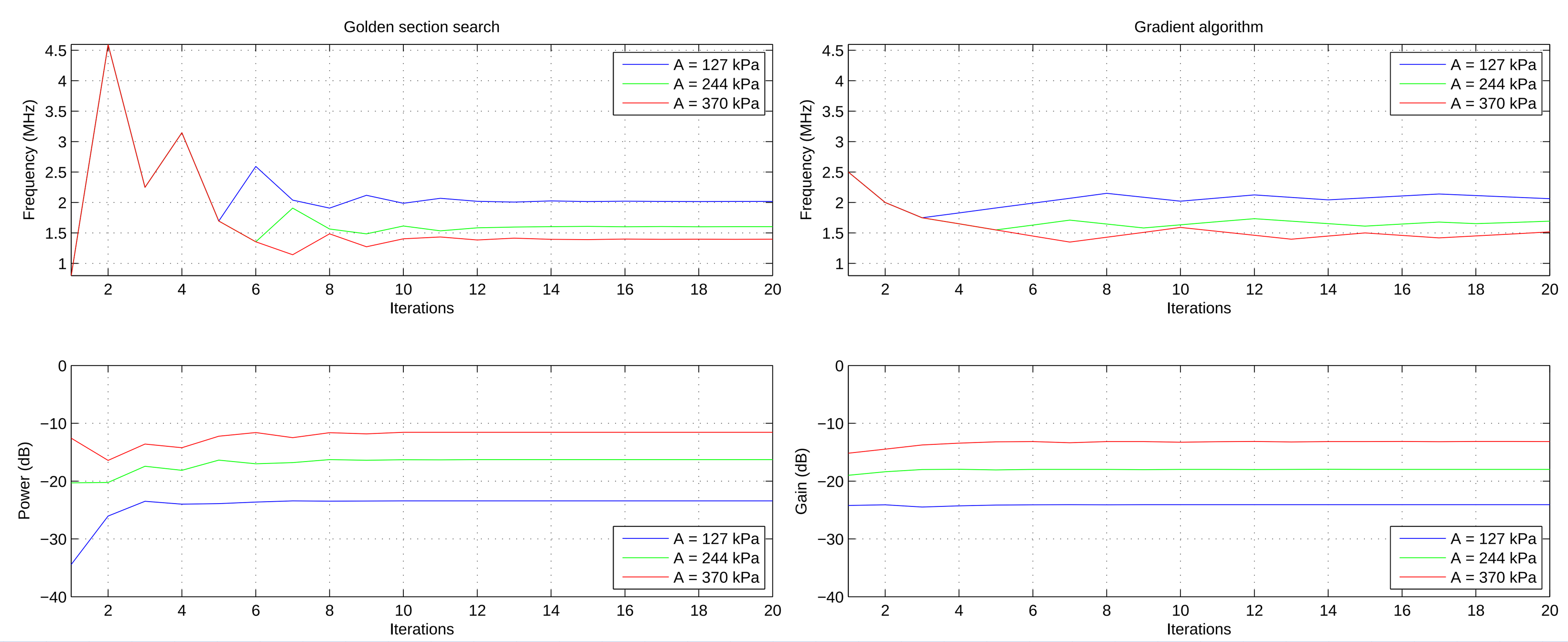


4. Results : simulation

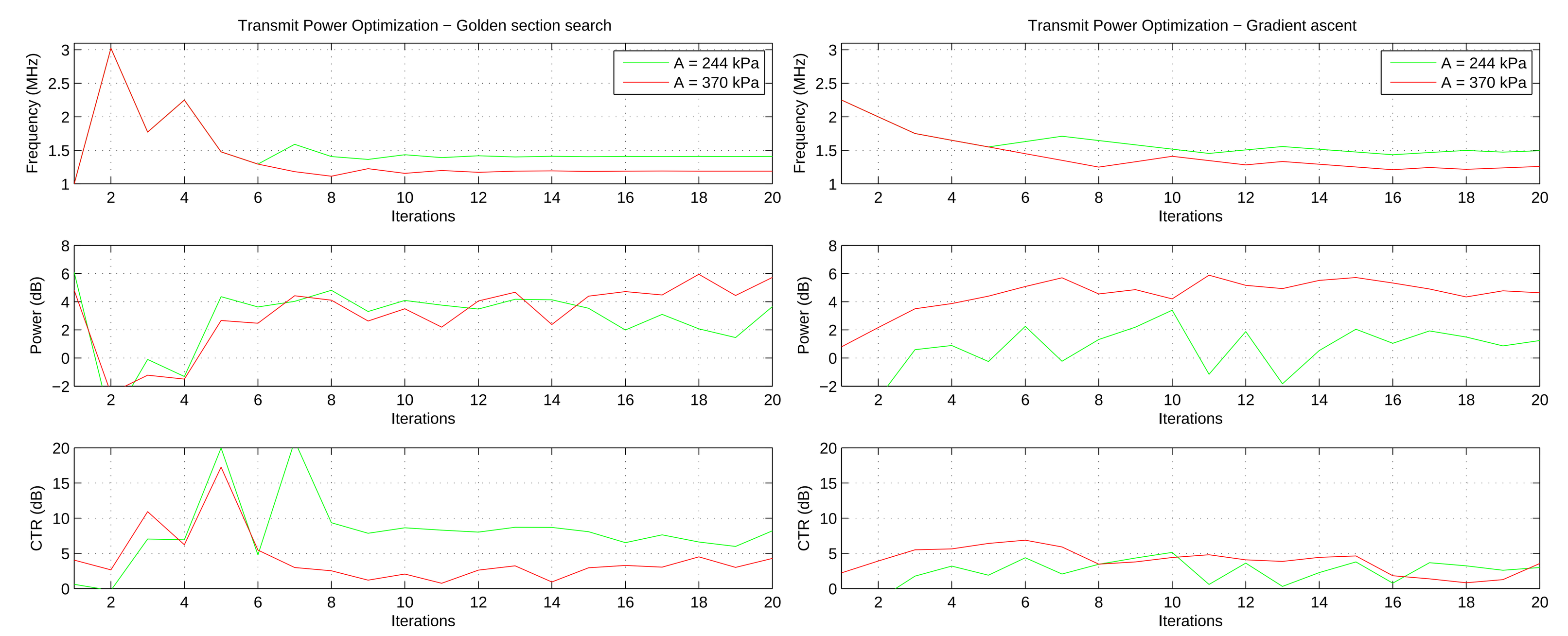
BubbleSim (Model based on modified Rayleigh-Plesset equation)



Backscattered Power	Pressure	Frequency
-17.4 dB	244 kPa	2.25 MHz
	222 kPa	1.65 MHz
-13.6 dB	370 kPa	2.25 MHz
	308 kPa	1.48 MHz



5. Results : experiments



Backscattered Power		Without	GSO	GA
5 dB	pressure (kPa)	244	222	222
	frequency (MHz)	2.25	1.45	1.18
	duration gain		21%	37%
6.6 dB	pressure (kPa)	370	305	305
	frequency (MHz)	2.25	1.61	1.27
	duration gain		13%	17%

The optimal frequencies depend on the transmitted pressure. The maximal power shifts forward the low frequency when the pressure increases.
The CTR is optimized with the maximization of backscattered power in around 10 iterations.

6. Discussion

In vitro, the power is computed for a cloud of microbubbles. To cancel the movements of the cloud, we repeat the experiment. A high number of repetition and a high number of iterations could destroy the microbubbles and thus the power could decrease. A trade-off must be found to avoid the destruction of the microbubbles.
By proposing a close loop system whose frequency adapt itself with the perfused media, throughout the examination, the optimization system adapt itself to the remaining bubbles population thus allowing an increase of the 37% examination duration.

7. Conclusion & future prospects

- The optimization permits to increase the backscattering energy. This gain increases the CTR.
- Increase of the 37% examination duration

- Simultaneous tissue echo minimization and microbubbles echo maximization
- Simultaneous adaptation in frequency and in amplitude

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